Full Use of GPS

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BIOGRAPHY

Captain Paul Novak was raised in Connecticut, and in 1973 he received a B.S. in Biology from Stonehill College, North Easton, MA. He is a graduate of the Aviation Officer Candidate School, and was designated a Naval Aviator in 1975.

He served as pilot for Sikorsky H-3 "SEA KING" helicopters and deployed aboard the U. S. Navy aircraft carriers world-wide while performing Helicopter Anti-Submarine Warfare missions. He was awarded a Masters of Science in Computer Systems Management in 1980 from the Naval Postgraduate School in Monterey, CA. He received the Navy Achievement Medal for a night rescue of 5 aviators in the Persian Gulf in 1981. In 1984 he became an Aerospace Engineering Duty Officer and served as SH-60B "SEA HAWK" Flight Acceptance Test Pilot at IBM Federal Systems Division, Owego, New York. In 1987 he became the Avionics Systems Project Officer for the LAMPS MK III, and the VH-3D and VH-60N Presidential Helicopters at to the Naval Air Systems Command Headquarters in Washington, DC. In 1990 he completed the Program Managers course at the Defense Systems Management College, FT Belvoir, VA, and was reassigned to the Naval Air Development Center, Warminster, PA where he led a team of 50 scientists and engineers delivering hardware and software products to the Fleet. In 1993 Captain Novak reported to the Space and Naval Warfare Systems Command, Washington, DC, where he directed the integration of Global Positioning System into over 100 configurations of U.S. Navy, Marine Corps, and Coast Guard aircraft. On 14 June 1996 he assumed command as Program Manager, Navigation Systems at the Space and Naval Warfare Systems Command where he is responsible for the integration of GPS into all U. S. Navy, Marine Corps and Coast Guard aircraft, and U.S. Navy ships and submarines.

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Bill Volkstadt is a 1955 graduate of the United States Military Academy with a Bachelor of Science degree in Military Engineering and a 1960 graduate of the University of Illinois with a Bachelor of Science degree in Electrical Engineering. He served in the United States Air Force at Wright-Patterson AFB as the Branch Chief for Fighter Avionics, at Andrews AFB as the Air Force Systems Command Chief of System Safety, and at Headquarters USAF, with duty station at the Federal Aviation Administration Headquarters, Wash D C, as the DoD representative for collision avoidance. He has supported the U. S. Navy NAVSTAR Global Positioning System (GPS) aircraft integration program since 1985. Mr. Volkstadt is an employee of DCS Corporation at Alexandria, VA.

ABSTRACT

Current Department of Defense (DoD) policy on the procurement and use of Global Positioning System (GPS) in the military departments dates back to 1992 and mandates the use of Precise Positioning Service (PPS) GPS User Equipment (UE) in all but a few DoD platform applications. Waivers must be must be submitted by the military departments for approval by the Office of the Secretary of Defense before procurement of any Standard Positioning Service (SPS) GPS UE or any GPS UE from sources other than the GPS Joint Program Office (JPO). The U.S. Coast Guard has fielded Differential GPS (DGPS), and the Federal Aviation Administration will soon be fielding their Wide Area Augmentation System (WAAS) and the Local Area Augmentation Systems (LAAS). Under current policy DoD will be unable to take advantage of these important developments and will not be able to derive the cost benefits and safety enhancements of these technologies unless a policy for the "Full Use of GPS and Augmentation Systems" is embraced. This paper will review the history of the current DoD GPS Policy, analyze the advantages and disadvantages of the current policy, and propose the concept of a new DoD policy that allows for the "Full Use of GPS and Augmentation Systems" for the military departments.

FULL USE OF GPS

The first third of the 1980's were ushered in by a conversation between Congress and the Department of Defense (DoD) concerning the cost of NAVSTAR Global Positioning System (GPS) and the advertised limited utility of this high cost system. Since inception in the 1970's, GPS had been advertised as a means to improve blind bombing accuracy when using low drag gravity bombs (dumb bombs). Congress was concerned that the cost was too great for support of this single purpose and suggested that DoD provide a more substantial argument, preferably one that would provide cost savings, if DoD desired to maintain continued Congressional support and funding.

Current events in the world of avionics at that time included great strides in digital avionics and the emergence of the Flight Management Computer System (FMCS). The significance of the capability to accomplish area navigation (RNAV) with the FMCS was not lost on the DoD planners. With this capability, they could use the Position, Velocity, and Time (PVT) solution from the GPS receiver in the FMCS to provide navigation data such as: desired course, track, ground speed, distance to destination, and cross track error.

Test and analysis demonstrated that the GPS RNAV data had significantly more accuracy then the radionavigation aids in use in conjunction with providing the unique capabilities of:

- Three dimensional velocity vectors
- Global coverage
- Continuous availability
- Passive service
- Common grid reference, and
- Common time reference

DoD was now able to return to Congress with the concept of TACAN emulation using GPS RNAV for operation in controlled airspace and the ability to reduce radionavigation costs by terminating operation of those facilities supplanted by GPS RNAV.

The emulation concept was developed in the GPS Phase in Steering Group as Minimum Avionics Requirements (MAR), which was accepted by the GPS Phase in Steering Committee (PISC) and promulgated as a DoD document. The MAR established the fundamental data development and display requirements necessary to take off, fly and recover to non-precision approach minimums in controlled airspace while remaining transparent to the Air Traffic Control (ATC) system. The transparent requirement came from the Federal Aviation Administration (FAA) Administrator. Transparent was defined, as performing all actions and responding to all directions in such a manner that the ATC controller could not discern that you were not using TACAN.

As the 1990's approached, the emerging technology of integrated circuits and the wide spread use of digital processors combined to provide the capability to produce inexpensive hand-held GPS receivers. Many enterprising new companies hit the marketplace with course acquisition (C/A) code receivers for the civilian market, which quickly gained acceptance with the surveying, pleasure boating and transportation communities. The advent and ensuing buildup of forces during Desert Shield resulted in the purchase of commercial C/A Code receivers by the GPS Joint Program Office (JPO), military units, and individuals to augment the limited number of military receivers in the inventory. The subsequent navigation success stories issuing from Desert Storm military actions provided the impetus for an exploding interest in GPS.

Air Carrier personnel, looking for cost reduction opportunities, had been evaluating the advantages of direct routing and separation reduction to reduce fuel consumption and to optimize flight profile. The results of the analysis showed that even for flight profiles that included several intermediate stops, the use of direct routing and optimum altitudes would result in several millions of dollars in savings, on an annual basis. The deregulation of the Air Carriers placed them in a highly competitive situation where any and all cost savings are significant in determining profit, which determines success. The Air Carriers had previously moved into Multi-sensor FMCS operations using VOR/DME and DME/DME for direct route RNAV and now were eager to use GPS in the regions that presented either too few ground facilities or bad geometry ground facilities to support controlled airspace operations. Their requests to the FAA initiated RTCA Inc. Special Committee activity to develop the structure for use of the GPS Standard Positioning Service (SPS) in controlled airspace to take off, fly and recover to non-precision approach minimums.
These activities initiated the divergence of DOD and civil policy since the civil community did not have access to the crypto keys required for use of the P (Y) code and the military community was and is committed to the use of the Precise Positioning Service (PPS) for military and controlled airspace operations.

The DOD is committed to operating the GPS System to provide SPS positioning accuracy of better than 100 meters horizontal (150 meters vertical) 95 percent of the time, and better than 300 meters horizontal (450 meters vertical) 99.99 percent of the time. SPS accuracy will increase at least an order of magnitude with the eventual turn-Off of S/A and the addition of an additional civilian frequency. RTCA SC-159 was formed to develop the Minimum Operational Performance Standards (MOPS) for the Airborne Equipment needed to implement the use of GPS navigation guidance in the National Airspace System (NAS). Early on in this development it was determined that implementing the necessary security controls in this open environment to protect the nature of S/A application would be too hard. Without a specific model, the investigators characterized the signal as possessing considerable uncertainty. Coupled with the system delay of fifteen minutes or more to detect and correct a system fault, the committee concluded that the SPS signal does not provide the accuracy, integrity, availability, and continuity of service required for service as a primary-means or sole-means system in the NAS.

The Civil Community and the FAA continued their efforts to overcome any shortcomings through SC-159 because of the significant benefits available to both aircraft operators and the ATC system. These benefits include:

- Precise 4-D (3 dimensions, plus time) navigation
- User preferred flight paths
- Reduced separation standards for more efficient use of the airspace
- Approach capability at all runways
- Cost savings from the phase out of ground based systems
- Reduced avionics systems with possible cost savings
- Simplified procedures resulting in reduced training cost

Initially, the civil community desired to use GPS as a Position, Velocity, and Time source for multi-sensor Flight Management Computers in support of Area Navigation solutions for enroute, terminal, and non-precision approach functions. This capability would provide the majority of benefits visualized for GPS. The characteristic of the GPS system that needed improvement for transition to Primary or Sole means operation was the response time to provide a warning to the users that the system should not be used for navigation. The ability to provide the warning in a timely fashion refers to the integrity of the system and has been equated to the 10-second response time of the Visual Omni Range (VOR). Traditionally, VOR integrity was assured by monitoring the transmitted signals and providing a warning when they are out of the specified value range. There is no direct correlation to an individual satellite since the signal in space error reflects into horizontal position errors by a complex function of the satellite geometry at the moment. A GPS integrity system must interpret the information it has about the pseudorange errors in terms of the induced horizontal position error and the make a decision on whether the error is outside a specified radial error. Specific radial errors have been specified for each phase of flight and are referred to as the alarm limit. The members of SC-159 pursued definition of both the GPS Integrity Channel (GIC) and Receiver Autonomous Integrity Monitoring (RAIM) as methods to deliver an integrity warning. Both of these methods have advantages and limitations.

RAIM is a completely self-contained consistency check of the GPS measurements that requires satellite signal redundancy with at least five satellites in view for an instantaneous solution. It has the added advantage that it is relatively easy to implement in software and may not require hardware changes or additions. Beside the need for more than four satellites in view, there are constraints in the satellite geometry that must be met for an effective check on consistency. Satellite outages therefore may cause RAIM holes.

GIC has the one advantage over RAIM in that the locations of the required monitor stations will be known precisely, and satellite redundancy is not needed to detect a satellite failure. The monitor stations will monitor all satellites in view and then relay the integrity data through geostationary satellites to the user. GIC limitations in the National Airspace (NAS) are only caused by system element failures, but without international implementation, GIC deteriorates rapidly outside the NAS.

The pioneering work in the maritime arena, which led to the implementation of Differential GPS (DGPS) data on the Marine Beacon by the United States Coast Guard, demonstrated the utility of this process for situations where greater precision is required.

DGPS test results indicated that the differential corrections could be used to successfully remove the uncertainty caused by S/A and provide greater accuracy than the baseline SPS signal for use by aviation. This capability was wedded with the GIC concept and expanded to encompass GPS ranging signals from the geostationary satellites. The resulting combination was given the title Wide Area Augmentation System (WAAS). The wide-area correction signals transmitted by WAAS allow the aircraft’s GPS/WAAS receiver to correct for the timing and ephemeris (satellite position) errors in the signals from each GPS or WAAS satellite and the signal delay due to the Earth’s ionosphere. With the addition of the WAAS satellite ranging signals and these corrections, GPS/WAAS is expected to meet the accuracy, availability, and continuity requirements for all phases of flight to include Category I precision approach. A derivative of the WAAS concept was desired by the civil aircraft community to provide Category I precision approach at popular airport facilities that did not have sufficient traffic or the physical characteristics required for an FAA sponsored Instrument Landing System (ILS). The RTCA responded by publishing a minimum aviation performance standard (MASPS) for special category I (SCAT-I) differential GPS system in August 1993, with a follow-up by the FAA with Order 8400.11 for the approval of SCAT-1 systems in August 1994. This activity increased the clamor from civil aviation for FAA commissioned DGPS precision approach facilities that would provide at least CAT-1 approach for all runway ends at the facility. The response from the FAA has been to develop the criteria for a Local Area Augmentation System (LAAS) and GPS/LAAS avionics with configuration options that support CAT-1, -2, and/or –3 precision approach. These activities by the civil community have established the criteria for obtaining the GPS benefits listed previously at the beginning of this article. During this developmental period, the use and significance of GPS has continually expanded to include many aspects of our technology-laden world. This transition to a world wide utility supplying precise position, velocity and time to a diverse set of users to include finance, surveying, bar codes, along with the initial intended use for navigation data, has caused the United States to commit itself to provide GPS free of charges, with the institution of additional civil signals and an absence of S/A. The effect that these changes along with improvements being introduced into the control and satellite segments will have on the augmentation systems has yet to be broached.

As the civil community developed augmentations to overcome the deficiencies of the SPS, S/A, and control segment update rate, the military services under DOD guidance pressed forward with their PPS implementation program. This guidance was issued in Memorandum form from the Assistant Secretary of Defense, Command, Control, Communications and Intelligence [ASD(C3I)] with Subject: Integration of Global Positioning System (GPS) to Fly in the National Airspace. The 11 May 1988 guidance included: “In November 1985 the ASD (C3I) informed the FAA Administrator that DoD intended to use GPS as the primary military navigational aid for en-route and terminal phases of flight in the National Airspace. In his response to ASD (C3I), the Administrator concurred with DoD plans provided that the use of GPS be essentially transparent to the current air traffic system.” If GPS-equipped DoD aircraft are to operate safely in the existing national airspace structure while being transparent to the current air traffic system, these aircraft must the be integrated in such a manner as to emulate TACAN/VOR/DME. Furthermore, a baseline integration guideline and minimum operational performance standards must be established.” The joint service response to this guidance was to develop the GPS Minimum Avionics Requirements (MAR) document and initiate procedure development through the United States Air Force Instrument Flight Center. The procedural development effort enlisted the aid of the FAA for data reduction on the many instrumented non-precision approaches flown was instrumental in changing the approach corridor from +/- 3 degrees to +/- 0.3 NM. The MAR was developed and coordinated through the GPS Phase in Steering Committee with help from the FAA, which had just completed a similar document for implementing LORAN-C non-precision approaches.

The Department of the Navy on 30 June 1988, issued specific GPS aircraft guidance “ to achieve the following characteristics:

a. The navigation system shall be capable of using GPS information (at Standard Positioning Service levels o accuracy) as the basis for navigation solutions displayed on the pilot’s flight instruments. This information should allow pilots to perform departure, enroute and non-precision approach procedures in accordance with standards developed by the USAF Instrument Flight Center.” This parenthetical SPS statement was made prior to the determination that additional criteria beyond accuracy were required to use SPS in the NAS.
b. “The navigation system shall be resistant to degradation of performance in the event of temporary loss of GPS signal reception due to reduced satellite visibility, vehicle dynamics, or jamming, and will exhibit graceful performance degradation when so affected.”
c. “GPS shall be utilized as the platform source of Universal Coordinated Time (UTC).”

These characteristics became Navy inputs to the developing MAR and became requirements based on the Nov. 28, 1988 Memorandum from AIR-01 of the Naval Air Systems Command (NAVAIR) which stated that: “CNO Joint Ltr Ser 943D/8U541361 of 17 Jun 88 and 05/8U593921 of 30 Jun 88 is to be viewed as an operational requirement for GPS.” This Memorandum also gave the guidance that: “Some form of data entry will be required to insert and select airway and approach information.” The Navy GPS Program Office (PMW/A-187) now had NAVAIR operational requirements to be used to establish a baseline integration design.

The specific design actions taken to support the functions of the operational requirements included:

- Participation in the Digital Aeronautical Flight Information File (DAFIF) proceedings to develop the necessary file formats for electronic transfer of controlled airspace waypoints. This effort resulted in the transition from nine track tapes to a CD ROM for the delivery of digital data to support TACAN emulation for enroute, terminal, non-precision approach and airport operations.
- Modification of mission planning station software and hardware to accept the CD

ROM and use the DAFIF files for transfer of data to a transfer device.

- Select a data transfer device that would be cost effective for provisioning most Navy, Marine Corps, and some Coast Guard Aircraft. Memory size was based on the ability to store multiple flight plans, a worldwide magnetic variation file, the GPS Almanac file, and a large quantity of individual waypoints along with a means to electronically check for errors.
- Establish the functional requirements for a control display unit [CDU] for the GPS system that would also assume the role of a FMC and Mil-STD-1553 Multiplex Data Bus. The results are encompassed in the Navy Control Display Navigation Unit [CDNU], which has become a stellar example for reuse of software developments with implementations in multiple installations.
- A joint service development of a Signal Data Converter [SDC] for conversion of the ARINC 429 digital signals delivered by the CDNU to analogue for driving the aircraft flight instruments

With the parts in place to emulate TACAN, the aircraft integration process was implemented to provide the functional capability to transport World Geodetic Survey 1984 [WGS 84] waypoint data to the RNAV processor onboard the aircraft to calculate desired track and distance to destination. Present PVT data is transported from the GPS receiver to the RNAV processor by the same multiplex bus for calculation of the navigation parameters, shipped to the flight instruments and displayed on the CDNU or MFCDU.

Military Service development of aircraft GPS systems has been based on the use of the basic precision signals, the use of the GPS crypto variables to obtain the precision signals, and emulation of TACAN. This approach was emphasized by the policy statements from DoD and the Service Departments as in for example the Jun 06 1996 Memorandum from the Under Secretary of Defense and the Chairman of the Joint Chiefs of Staff, Subject: Use of GPS in Controlled Airspace. “We request the Air Force Director of Operations take the lead, through the GPS Phase-In Steering Committee (PISC), in considering what must be done by the DoD to use the GPS Precise Positioning Service (PPS) to conduct flight operations in controlled airspace…Specifically, the PISC should determine the actions necessary to implement the operational policies, equipment and/or software modifications, flight operations standards, documentation, procedures, and other system integration and support requirements to enable DoD aircraft to take off, fly and recover to non-precision approach minimums anywhere in the world without reference to ground-based radionavigation aids.”

The Joint Precision and Landing System (JPALS) Mission Needs Statement (MNS) started the DoD look at Differential GPS (DGPS) since it required a close look at the technology available to step in the gap with the demise of MLS as a universal solution for precision approach. The Analysis of Alternatives (AOA) for JPALS picked augmented GPS as a prime candidate for the precision approach technology for the future, with the major difference still the use of the protected PPS as opposed to civil use of SPS.

DoD policy makers are today faced with a vastly different situation than their predecessors in 1988 when the P (Y) code in the NAS to emulate TACAN and remain transparent to the ATC decision was made. In the interim, the civil world has flocked to GPS in numbers that dwarf the military. Presidential policy has made GPS a universal utility with the promise to maintain the system, provide ample warning if for any reason the system was to be changed or abandoned, and review the SA policy with the most likely result of returning full accuracy of SPS by setting SA to zero in 2006. This was followed by Vice Presidential announcements of a second SPS signal which can be used to remove the significant errors caused by ionosphere delays and a third frequency carrying the civil signal on a clear aeronautical channel.

The wide spread use of GPS by the civil community, the perceived financial savings by substituting GPS for other radionavigation aids, and the investment by the civil community in GPS equipment and augmentation systems has led to a Presidential decision to control GPS future development through an Interagency GPS Executive Board (IGEB) which is Co-Chaired by DoD and DoT. Under this arraignment, DoD exercises operational control over the GPS basic system and are charged with preserving friendly use, denying adversary use, and not disrupting civil use.

The DRAFT 1999 CJCS Master Positioning, Navigation and Timing Plan in defining DoD Differential Policy states: “The DoD will operate insofar as possible using the PPS received directly from the GPS satellite constellation as the primary source of PNT information. Additionally, the DoD is considering methods to improve the direct reception accuracy available from PPS to satisfy high-

precision positioning, timing, and navigation needs in authorized military platforms without requiring differential corrections.” but,
“DoD GPS users may use civilian-provided SPS-based DGPS services when civil agencies have defined navigation accuracy, integrity, availability, and continuity of service requirements that exceed direct reception PPS capabilities, where operation is in the interest of the Department of Defense, and where such use will not result in adverse effects to military missions.”

The sailing orders have been given. It is now incumbent on the policy implementers in DoD to devise the means to take advantage of the technological advances produced by the ground swell of interest in the civilian community, to determine how and when to use it, and still meet the military mission requirements. Some of the military aircraft retain FAA certification and will use civil equipment with a Technical Standard Order (TSO) GPS as basic and obtain a Supplemental Type Certificate (STC) for operations. These aircraft that also fly combat support will require military PPS equipment for those circumstances. The opposite may be true for combat aircraft for peacetime operation in controlled airspace, especially when the specified navigation requirement cannot be met with PPS. It will take a concerted effort by the GPS community to resolve this issue economically.

REFERENCES

1. DOD-4650.5/DOT-VNTSC-RSPA-97-2, 1996 Federal Radionavigation Plan.
2. Assistant Secretary of Defense Memorandum, 11 May 1988, Subject: Integration of Global Positioning System (GPS) to Fly in the National Airspace.
3. Department of the Navy, Office of the Chief of Naval Operations, 17 Jun 1988/30 Jun 1988, CNO 3500 Ser 943D/8U541631 and Ser 05/8U593921, Subject: NAVSTAR Global Positioning System (GPS) Aircraft Integration Guidance.
4. Department of the Navy, Naval Air Systems Command, Memorandum, Nov 28, 1988, Subject: Global Positioning System (GPS) Aircraft Integration
5. Assistant Secretary of Defense, 11 May 1988, Memorandum, Subject: NAVSTAR Global Positioning System (GPS) User Equipment (UE) Acquisition Plan.
6. Assistant Secretary of Defense, Memorandum 13 Sep 1991, Subject: DoD Minimum Avionics Requirements (MAR) for Global Positioning System GPS Sole Means Navigation.
7. Assistant Secretary of Defense, Memorandum April 30, 1992, Subject: Development, Procurement and Employment of DoD Global Positioning System (GPS) User Equipment.
8. Assistant Secretary of Defense, Memorandum, October 12, 1993, Subject: Guidance for Integration of Global Positioning System (GPS) Equipment in DoD Aircraft.
9. Naval Message, 101202Z Jun 94, CNO Washington DC//N6, Subject: Global Positioning System (GPS).
10. Under Secretary of Defense (A&T) and Vice Chairman Joint Chiefs of Staff, Memorandum, Jun 06, 1996, Subject: Use of Global Positioning System (GPS) in Controlled Airspace.
11. Department of the Navy, Ser N880G2/4U659781, 7 Jun 1994, Subject: CNO GPAS Integration Guidance.
12. The White House, Science and Technology Policy National Security Council, March 29, 1996, Fact Sheet, U.S. Global Positioning System Policy.
13. Office of the Administrator, Jul 26, 1996, FAA’s Plan for Transition to GPS-Based Navigation and Landing Guidance.
14. CJCSI 6130.01A, 13 February 1998, 1998 CJCS Master Positioning, Navigation, and Timing Plan.
15. The White House, August 12, 1998, Memorandum, Subject: Implementation of the Administration’s Global Positioning System (GPS) Policy.